MICROWAVE FINISHING OF POTATO CHIPS: EFFECT ON THE AMINO ACIDS AND SUGARS[1]

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INTRODUCTION

Among the reactions which take place during the preparation of potato chips, it is commonly recognized that the most important are those which cause the browning of the product. These involve the carbonyl-amino reactions including the reaction of reducing sugars and other aldehydes and ketones with amines, peptides and proteins.

It is generally agreed that the actual formation of browning substances occurs through a combination of sugar-amine condensation, Amadori rearrangement, sugar and amino acid degradation, aldol condensation and aldehyde-amine polymerization.

In two previous studies (3, 4), the frying of chips from stored potatoes having a high reducing sugar content resulted in a sharp reduction in both reducing sugars and free amino acids. In both studies there was little change in the total nitrogen. It was concluded that sugar-amino acid reaction products had formed and for the most part had proceeded to the polymeric stage resulting in the browning of the chips.

Anet and Reynolds (1) have shown that reactions between sugars and amino acids can occur at lower temperatures. These workers, using ion exchange techniques with a ninhydrin indicator, have isolated several sugar-amino acid reaction products (1-amino-1-deoxy-2-ketoses) from freeze dried apricot and peach purées with a corresponding loss of the original sugars and amino acids.

Talley and Porter (11) also demonstrated that sugars and amino acids in model systems would react when allowed to stand at room temperature. These workers added substantial evidence to the theory that initial sugar-amino acid reaction products are colorless intermediates in the subsequent formation of brown pigments.

It was thought that the problem of chip browning might be solved if the series of reactions involved could be interrupted at some point before the occurrence of polymerization. Microwave finishing, a revolutionary new procedure for processing potato chips, may be one answer to the problem. This method utilizes the conventional frying methods to remove about 90% of the moisture present in potato slices. The remaining moisture is removed electronically, by the use of microwave energy, at a relatively low temperature.

This procedure has been shown to incorporate many advantages from a product viewpoint. Potatoes having a glucose content as high as 0.75% can be processed into chips of satisfactory color. Oil uptake is less and total time for preparation is shortened. Both of these result in a lower cost of processing. There is also a delay in the development of rancidity in chips that have been microwave finished, resulting in a product with a longer shelf life (2).

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From a technical point of view, however, the main advantage to microwave finishing of potato chips is that the chain of non-enzymatic browning reactions has been interrupted before the point of polymerization. The formation of undesirable brown pigments by excessive polymerization is inhibited because the temperature of the potato chips never exceeds, to any great extent, the boiling point of water. In contrast to microwave finishing, the chip temperature in deep fat frying rises to the temperature of the frying oil (300 F or higher) during the final stages of moisture removal.

With the advent of microwave finishing it has become increasingly important that knowledge be obtained concerning the fate of sugars and nitrogenous materials in potato chips processed in this manner. Therefore, this study was undertaken to follow the complex pattern of free amino acids, amides, reducing sugars and total sugars as affected by microwave finishing as compared to conventional fat frying, both on chips from freshly harvested potatoes and on chips from tubers which had undergone prolonged storage in the cold.

Materials and Methods

Katahdin potatoes grown in Pennsylvania were procured a few hours after harvest. When received, these tubers tested with the Potato Chip Institute International (PCII) test paper, gave a reading of less than 0.1% for glucose. Sampling and testing of the potatoes were carried out using the techniques reported in a previous publication (4). Replicate samples of the tubers were retained for the analysis of the fresh stock and of chips prepared from them by conventional deep fat frying and by prefrying followed by microwave finishing. The remaining samples of potatoes were stored at 36 F for 5.5 months. At that time they were withdrawn for the analysis of stored potatoes and of chips made from them by the two procedures mentioned above. After low temperature storage, the tubers tested with PCII paper gave a reading for glucose of between 0.25% and 0.5%.

The potatoes and chips from both samples (fresh and stored) were analyzed in the same manner. After abrasion peeling, direct total solids and total nitrogen determinations (by Kjeldahl) were made on the potatoes.

Chips of both fresh and stored potatoes to be treated conventionally were fried batchwise in a basket-type fryer at 340 F for about 4 minutes. At this point the chips were crisp but not completely dehydrated.

Chips of fresh potatoes were prefried and microwave finished in the following manner. Replicate samples of the fresh tubers were sent to Dr. Ora Smith at Cornell University.[3] These potatoes were prefried in oil at 360 F for an average of 2 minutes which resulted in an average moisture content of 10.5%. These chips were then subjected to a finish period in a microwave oven at 2425 mc/sec. for an average time of 55 seconds.

Upon receipt of these chips at our Laboratory in Philadelphia, the fat was extracted from them with Skellysolve B and its level of uptake was found to be 3% less than that of the conventionally fried chips.

The chips from tubers stored in the cold were treated in much the

[3]When the fresh potatoes were available our microwave oven had not been received. Therefore Dr. Ora Smith at Cornell University was kind enough to prepare the microwave finished samples of chips from the freshly harvested potatoes.

same manner except that the entire chipping procedure was carried out at our laboratory. Duplicate samples of the potato slices were prefried in oil at 340 F for 3 minutes. At this point the light colored chips had an average moisture content of 12.3%. The chips were then finished in a microwave oven (Litton Model 500, 2450 mc)[4] for 2 minutes. Defatting these chips with Skellysolve B revealed that, in this case, the fat uptake was the same as that of the conventionally fried chips of the stored tubers.

The amino acids and sugars were extracted from all samples of both tubers and chips according to the procedure of Talley et al. (10). Nitrogen analyses (by Kjeldahl) were made on all of these extracts. Analyses for total and reducing sugars by the method of Spengler, Tödt and Scheuer (9) were also carried out. Amino acid analysis was conducted by the method of Spackman, Stein and Moore (8) using a Phoenix Model K-5000 amino acid analyzer[4] coupled to an analog to digital converter (6), the output of which was processed on an IBM Model 1130 computer.[4]

Results and Discussion

A local variety of potatoes, viz. Pennsylvania Katahdins, was used to reduce the possibility of sugar accumulation due to storage prior to experimentation.

Nitrogen — The agreement in total solids between the fresh and stored tubers, as shown in Table 1, accompanied by a weight loss of about 5% in the stored tubers indicates that during storage, solids and moisture were lost in the ratio of the original composition and agrees with the findings of Treadway et al (12). This loss resulted in an apparent increase of the total and extractable nitrogen in the stored samples. However, the percent of the extractable nitrogn from the completely fat fried chips of both fresh and stored potatoes remained constant. This indicated that an increasing amount of this non-protein nitrogen was being converted to non-extractable compounds. These findings agree with work previously reported (3).

This constant level in the per cent of extractable nitrogen was not evident in the case of the microwave finished chips of both fresh and stored potatoes. An increase in the nitrogen of the tubers during storage was accompanied by an increase in the per cent of extractable nitrogen in chips that were microwave finished. This may be explained by the fact that these chips contained quite large amounts of extractable amino acid-sugar reaction products (intermediates) that were not further degraded. These nitrogen relationships are expressed in Table 1.

Amino acids. — The results of the complete amino acid analysis of the fresh and stored potato extracts and extracts of chips made from them, both by conventional frying and microwave finishing, appear in Table 2. Several unknown peaks are listed and reported as leucine equivalents. The effluent volumes of most of these unknowns were in close agreement with those reported by Ingles and Reynolds (5) for amino acid fructoses although their methods of separation were slightly different. The magnitude of these compounds was relatively minor in all of the extracts except that from the microwave finished chips of the stored

[4]Mention of a specific piece of commercial equipment does not imply endorsement by the U. S. Department of Agriculture over similar equipment available.

TABLE 1.—*Solids and nitrogen content of Pennsylvania Katahdin potatoes and chips.*[1]

Sample	Solids %	Total N in starting material %	Nitrogen In extract %	Nitrogen Extractable %
Fresh potatoes	20.08	0.428	0.236	55.14
Chips from fresh potatoes				
Fat fried	19.21	0.428	0.237	55.37
Microwave finished[2]	18.89	0.445	0.252	56.63
Stored potatoes	20.84	0.500	0.308	61.60
Chips from stored potatoes				
Fat fried	20.30	0.475	0.263	55.37
Microwave finished[3]	18.60	0.449	0.260	57.91

[1]Calculated on fresh tuber basis.
[2]Average of 60 sec. at 2425 mc/sec.
[3]Average of 120 sec. at 2450 mc/sec.

potatoes. From this source these compounds appeared as major components, particularly those in the more acid region of the chromatogram. The increase in the amount of these materials in the high reducing sugar potatoes, which were not subjected to the excessive temperatures of complete dehydration in hot oil, gave credence to the theory that these materials could be amino acid fructoses which had not undergone further reaction to form dark pigments.

It can be observed from Table 3 that conventional deep fat frying of both fresh and stored potato chips caused decreases in amino acid nitrogen (as measured by ninhydrin reactivity) of about 22% in the case of fresh chips, but almost double that amount in the chips with an accumulation of reducing sugars from prolonged cold storage of the tubers.

This decrease in amino acid nitrogen occurred even though these chips were not dehydrated completely but fried to a uniform crisp texture only. These high sugar chips were quite dark in color. Losses were not specific for any particular amino acid but a marked decrease in the amides was evident. In chips fried from the fresh tubers, this loss was offset by a sufficient increase in ammonia to indicate deamidization but this was accompanied by a decrease in glutamic acid indicating that the loss even in low sugar potatoes, was due to more than normal degradation.

In the case of the microwave finished chips, the amino acid losses were considerably less, reaching about 22% in the high sugar containing chips and only slightly over 5% in the chips from fresh potatoes. It is highly possible that some peaks of known amino acids may be inflated or at least maintained by the presence of undetected amino acid fructoses having similar effluent volumes. The increase in β-alanine in both the fresh and stored potato chips which had been microwave finished, for example, is suspected to be due to this coincidence. The color of the microwave finished chips from both fresh and stored potatoes was the

TABLE 2.—*Amino acid analysis of potato chip extracts.*[1]

Acino acid	Vol.[2]	Fresh extracts			Stored extracts		
		Potato	Fat fried chip	Micro-waved chip	Potato	Fat fried chip[3]	Micro-waved chip[3]
Unknown[4]	47	0.46	0.55	0.63	0.41	0.55	0.92
Unknown	57	0.20	0.13	0.44	0.24	0.26	0.42
Unknown	64	0.18	0.30	0.50	0.27	0.11	0.78
Unknown	81	0.13	0.11	1.12	0.18	0.56	3.48
Unknown	100	0.14	0.06	0.77	0.74	2.46	15.79
Unknown	115	0.82	1.57	1.79	0.86	1.81	5.85
Methionine Sulfoxides 1	118	0.39	2.01	1.99	0.99	1.10	1.30
Methionine Sulfoxides 2	122	0.31	1.42	1.31	0.09	0.61	1.03
Aspartic Acid	145	22.61	22.99	27.07	23.02	22.51	22.24
Threonine	153	4.18	2.97	3.59	5.59	3.62	4.45
Serine	166	7.97	7.99	8.33	9.32	6.96	8.89
Glutamine[5] Asparagine	185	223.80	412.05	192.21	303.47	158.05	212.75
Proline	220	3.80	4.20	6.70	8.02	8.85	7.22
Glutamic Acid	240	22.72	9.33	19.45	25.96	16.21	16.88
Glycine	278	2.22	2.66	3.17	2.30	1.61	1.84
Alanine	292	5.18	6.84	5.51	6.09	7.14	5.69
Unknown	343	0.32	0.39	0.12	0.65	0.00	0.28
Valine	362	16.81	17.61	18.39	22.49	15.52	18.69
Buffer Change	419	0.43	1.03	0.60	0.32	0.91	0.52
Unknown	427	0.17	0.00	0.10	0.29	0.23	0.23
Methionine	434	6.89	3.47	4.94	4.85	1.85	2.92
Isoleucine	445	7.43	10.72	8.74	9.91	6.65	8.49
Leucine	463	3.65	3.72	3.08	4.79	2.92	4.31
Unknown	522	0.00	0.07	0.00	0.00	0.35	3.19
Tyrosine	533	6.64	6.88	6.65	11.18	7.01	9.17
Phenylalanine	547	6.15	5.79	5.21	8.35	4.50	6.47
Unknown	576	0.00	0.00	0.00	0.06	0.00	1.80
β-alanine	598	0.90	1.30	1.53	0.98	0.68	1.17
Unknown	137	0.00	0.21	0.23	0.00	1.78	3.05
γ-aminobutyric acid	184	23.20	18.83	23.77	27.02	18.00	20.76
Ornathine	203	0.12	0.17	0.18	0.69	0.34	0.48
Ethanolamine	229	0.80	0.80	0.72	0.92	0.17	0.16
Ammonia	245	8.19	34.64	29.66	16.29	32.77	30.37
Lysine	261	5.03	4.56	5.89	8.40	3.94	5.69
Unknown	303	0.00	0.13	0.10	0.00	0.25	0.24
Histidine	321	4.04	3.77	3.59	6.05	2.98	4.69
Unknown	392	1.15	1.55	1.09	1.78	1.12	1.57
Unknown	496	0.00	0.12	0.00	0.03	0.15	0.00
Arginine	615	13.30	12.33	11.59	23.79	13.49	16.48
Total μmols N/g Dry Wt.[6]		677.26	524.58	640.99	931.52	558.49	724.84

[1]Reported as μmols/g Dry Wt. Average of duplicate runs.
[2]Relative effluent volume. First series = Acid and nutral, Second series = basic amino acids.
[3]Stored chip extract = extract of chips made from stored potatoes.
[4]All unknown peaks calculated as leucine equivalents.
[5]Reported as asparagine.
[6]Adjusted for multiple nitrogen compounds.

TABLE 3.—*The effect of fat frying versus microwave finishing on extractable potato nitrogen.*

Extract sample	Extractable N (Kjeldahl) μ mols/g dry wt.	Free amino acid N[1] Recovery μ mols/g dry wt.	Free amino acid N[1] Loss on frying %	Extractable N recovered as free amino acids[1] %
Fresh potato	839.5	677.3		80.67
Fresh chip				
Fat fried	854.6	524.6	22.54	61.38
Microwave finished	952.9	641.0	5.36	67.27
Stored potato	1055.6	931.5		88.25
Stored chip[2]				
Fat fried	925.4	558.5	40.05	60.35
Microwave finished	998.4	724.8	22.19	72.60

[1]Also includes amides and unknown peaks on analyzer.
[2]Extract of chips made from stored potatoes.

TABLE 4.—*The effect of fat frying versus microwave finishing on the sugars of potato chips.*

Extract Sample	Reducing sugars[1] μ mol/g dry wt.	Reducing sugars[1] Loss on frying %	Non-reducing sugars[2] μ mol/g dry wt.	Non-reducing sugars[2] Loss on frying %	μ mol/g dry wt.	Loss on frying %
Fresh potato	60.83		35.41		96.24	
Fresh chip						
Fat fried	11.05	81.8	31.99	9.66	43.04	55.28
Microwave finished	18.10	70.2	32.25	8.92	50.35	47.68
Stored potato	185.67		45.40		231.07	
Stored chip[2]						
Fat fried	55.17	70.3	25.77	43.24	80.94	64.97
Microwave finished	139.60	34.8	30.10	33.70	169.70	26.56

[1]As fructose.
[2]As sucrose.
[3]Extract of chips made from stored potatoes.

same in both cases, each having an approximate value of 4 on the PCII color chart. Finally, the same spectrum of twenty-four amino acids and amides was identified and measured in the chips prepared by microwave finishing and in chips conventionally fat fried, and agrees with that found in different varieties of potatoes grown in different areas of the country (3, 4).

Sugars. — The losses of sugars during chip processing both by conventional deep fat frying and by microwave finishing generally followed the respective losses of amino acids, and agreed with previous work done at this laboratory (3, 4). Table 4 shows that deep fat frying caused a

greater loss in both reducing and in total sugars than did microwave finishing. This was considerably more pronounced in the chips from the stored potatoes which had accumulated a high reducing sugar content. In this case, deep fat frying of chips caused a loss of reducing sugars almost three times that incurred by microwave finishing. It is assumed that at least a portion of this loss was due to reaction with amino acids.

The apparent parallel loss of reducing sugars and amino acids may not necessarily be due to the same reactions. The decrease in reducing sugars is probably due to the Maillard reaction which results in the formation of highly colored polymeric materials, the amino acids acting as catalysts for the reaction. The decrease in amino acids may be due to the Strecker degradation in which α-amino acids are decarboxylated to form aldehydes containing one less carbon atom. In this reaction amino groups are liberated as ammonia or remain linked to the carbonyl compound which caused the degradation (7). Since no loss of total nitrogen was observed in any of the chip extracts the latter explanation is probably valid.

Summary

The losses of both amino acids and sugars (especially reducing sugars) was greater in chips prepared by conventional deep fat frying than in chips which were finish dehydrated in a microwave oven. These losses were considerably amplified in chips from potatoes with a high reducing sugar content. Unknown materials of significant magnitude were found in the microwave finished chips prepared from high reducing sugar containing potatoes. These were assumed from their effluent volumes to be amino acid-fructose intermediates which had not reacted further to polymeric brown pigments as occurred in the samples fried in deep fat. Twenty-four free amino acids and amides were identified and measured in these potatoes (Pennsylvania Kathdins) and in the chips. Using microwave energy it was possible to prepare potato chips of light color and desirable quality from potatoes containing almost 0.5% glucose.

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Resumen

La pérdida tanto de amino ácidos como de azúcares (especialmente azúcares reductores) en papas fritas preparadas de la manera acostumbrada friéndolas en aceite fué más grande que en papas fritas que fueron dehidratadas en una estufa de micro-onda. Estas pérdidas fueron especialmente prominentes en papas fritas obtenidas de papas con un contenido alto en azúcares reductores. Materiales desconocidos en cantidad significante fueron encontrados en papas fritas por el método de micro-onda obtenidas de papas con alto contenido en azúcares reductores. Por razón del volumen de sus efluentes se pensó que estos materiales eran intermediarios de amino ácidos y fructosa que fallaron de transformarse en pigmentos pardos poliméricos como ocurre en papas que se fríen en aceite. Veinticuatro amino ácidos libres y amidos fueron identificados y medidos

en estas papas (Pennsylvania Katahdin) y en papas fritas. Empleando la energía de micro-onda fué posible obtener papas fritas de un color ligero y de una calidad deseable de papas que contenían casi 0.5% de glucosa.

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